X-RAY IMAGING SYSTEM WITH AUTOMATIC IMAGE RESOLUTION ENHANCEMENT

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to x-ray imaging systems, and in particular, to automated x-ray imaging systems capable of providing selectively enhanced image resolutions, e.g., for magnifying the field of view and providing a display image having features not otherwise visible to an unaided human eye.

2. Description of the Related Art

[0002] Medical x-ray imaging has been and continues to be a very important tool for medical diagnostics. Such systems typically use x-ray film or digital electronic image sensors to record the intensity of the photons that pass through the subject. Conventional automatic exposure systems are often used to control the x-ray exposure by controlling things such as the voltage or current driving the x-ray source or controlling the exposure time to achieve the best exposure to the entire volume of the subject being imaged. Such systems use a signal acquired at the exit side of the subject of the x-ray imaging to control the exposure. In those systems using film, detectors, placed either in front of or behind the film, generate one or more signals based on the amount of x-ray exposure received. These detectors, calibrated to the film being used, provide signals which can be processed to determine and control the overall exposure. In those systems using electronic image sensors, the image

signals provided by the sensor array can be used directly for monitoring the exposure and providing appropriate control signals.

[0003] Following completion of the x-ray imaging itself, the image in its film or electronic form is then typically checked for image quality by the attending technician. Later, that same film or electronic image is checked by a specialist, e.g., a radiologist, and a diagnosis is performed. Depending upon the results of the diagnosis, the subject may be brought back for additional x-ray imaging of the region or regions found to be of greater interest following the diagnosis. Such subsequent imaging will typically be performed with the collimator adjusted to focus on the specific regions of interest, and increased x-ray doses will be applied.

[0004] Images generated using x-ray radiation are often degraded by scattering of the radiation, low signal-to-noise ratio (caused by a desire for exposing the subject to as minimum a radiation dose as possible), requirements for large dynamic range, and saturation of the sensors used in the detector array (caused by x-ray radiation striking the imager without attenuation). While these problems can be minimized by the attending technician using collimators to isolate a region of interest, such technician is generally not qualified to read the images or determine the appropriate areas of interest. Further, during many procedures, the patient is under some discomfort during the procedure and is, therefore, removed from the imaging system prior to any reading of the film or image. Accordingly, significant percentages of subjects are recalled for additional imaging.

[0005] Accordingly, it would be desirable to have an x-ray imaging system capable of determining, focusing upon and selectively increasing, in a real time manner, the image resolution of the regions of the subject being of the most interest.

SUMMARY OF THE INVENTION

[0006] In accordance with the presently claimed invention, an automated X-ray imaging system and method are provided for producing a plurality of X-ray imaging signals having selectively enhanced image resolutions, e.g., for magnifying the field of view and providing a display image having features not otherwise visible to an unaided human eye. Successive doses of X-ray radiation are applied to a portion of the subject to produce corresponding image signals. Such doses of X-ray radiation are controlled by controlling X-ray radiation characteristics, such as intensity, focal spot size, focal spot location, focal spot shape, or collimation, to cause a subsequent image signal to differ from a prior image signal in one or more image characteristics, such as image resolution.

[0007] In accordance with one embodiment of the presently claimed invention, an automated X-ray imaging system for producing a plurality of X-ray imaging signals includes an X-ray emission system, an X-ray detection system and a control system. The X-ray emission system is responsive to at least one emission control signal by providing at least first and second doses of X-ray radiation, wherein the second dose differs from the first dose in one or more of a plurality of X-ray radiation characteristics. The X-ray detection system is responsive to at least one detection control signal and is for placement in relation to the X-ray

emission system to be responsive to respective portions of the first and second doses of X-ray radiation following exposure thereto of a portion of a subject disposed substantially between the X-ray emission and detection systems by providing corresponding first and second image signals. The control system, coupled to the X-ray emission and detection systems, is responsive to the first and second image signals by providing the emission and detection control signals, wherein the second image signal differs from the first image signal in one or more of a plurality of image characteristics.

[0008] In accordance with another embodiment of the presently claimed invention, a automated method for producing a plurality of X-ray imaging signals includes:

receiving at least one emission control signal;

generating, in response to the at least one emission control signal, at least first and second doses of X-ray radiation, wherein the second dose differs from the first dose in one or more of a plurality of X-ray radiation characteristics;

receiving respective portions of the first and second doses of X-ray radiation following exposure thereto of a portion of a subject;

receiving at least one detection control signal;

generating, in response to the at least one detection control signal and the respective portions of the first and second doses of X-ray radiation, first and second image signals;

processing the first and second image signals; and

generating, in response to the processed first and second image signals, the emission and detection control signals, wherein the second image signal differs from the first image signal in one or more of a plurality of image characteristics.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Figure 1 is a functional block diagram of an x-ray imaging system in accordance with one embodiment of the presently claimed invention.

[00010] Figure 2 is a functional block diagram of a control system of Figure 1.

[00011] Figure 3 is a diagram depicting the selective collimation and resulting image resolution enhancement using an x-ray imaging system in accordance with the presently claimed invention.

DETAILED DESCRIPTION OF THE INVENTION

[00012] The following detailed description is of example embodiments of the presently claimed invention with references to the accompanying drawings. Such description is intended to be illustrative and not limiting with respect to the scope of the present invention. Such embodiments are described in sufficient detail to enable one of ordinary skill in the art to practice the subject invention, and it will be understood that other embodiments may be practiced with some variations without departing from the spirit or scope of the subject invention.

[00013] As discussed in more detail below, an x-ray imaging system in accordance with the presently claimed invention improves diagnostic x-ray image quality by using real-time computer analysis of an initial image, following which multiple images of regions of interest are taken using optimized imaging parameters. Optimization of the x-ray parameters includes collimation of the x-ray beam to the region of interest, as well as controlling focal

spot size, focal spot location, focal spot shape, x-ray tube voltage or current, and bias or dynamic range of the detector.

[00014] Referring to Figure 1, an x-ray imaging system 10 in accordance with one embodiment of the presently claimed invention includes an x-ray transmitter 12 and an x-ray detector 14, between which the subject 9 for the image is to be placed. Such components 12, 14 are conventional in nature. For example, the x-ray transmitter 12 will include an x-ray radiation source 12a, such as an x-ray tube, which is well-known in the art. Additionally, a controllable collimator 12b is used, as discussed in more detail below, to collimate, i.e., focus, the emitted x-ray radiation 13a to which the subject 9 is exposed.

[00015] The resulting x-ray radiation 13b which exits the subject is detected by a conventional detector assembly 14a which produces corresponding pixel signals 15a which are processed by the processor 14b into image signals 15b.

[00016] Such detector assemblies 14a are well known in the art. Examples of such a detector assembly 14a is include those implemented as a solid state electronic image sensor array in which a semiconductor (e.g., amorphous silicon (a-Si) or amorphous selenium (a-Se)) detector array is arranged as a two-dimensional matrix of pixels, each of which consists of a photosensitive element (e.g., photodiode or photoconductor) and a transistor switch (e.g., thin film transistor (TFT)). Similar to x-ray film cassettes, such a detector array is covered with a scintillation layer to convert the impinging x-rays into visible light for the photosensitive elements. (Further discussion of an x-ray imaging system using such a detector assembly can be found in U.S. Patent No. 5,970,115, entitled "Multiple Mode Digital X-ray Imaging System", the disclosure of which is incorporated herein by reference.)

[00017] Additionally, in accordance with the presently claimed invention, a control system 16 is used which, as discussed in more detail below, processes the image signals 15b to determine regions of interest within the subject. Once such region or regions of interest have been identified, the control system 16 provides appropriate detector control signals 17a and x-ray control signal 17b, which include specific control signal 17ba, 17bb for the x-ray source 12a and collimator 12b.

[00018] Referring to Figure 2, the control system 16 includes a processor 160, memory 162 for the incoming image data 15b, memory 164 for reference image data, and a controller 166 for generating the control signals 17a, 17b for the detector 14 and x-ray transmitter 12, all interconnected substantially as shown. The incoming image data 15b from the detector assembly 14 is stored in a memory 162. The stored memory data 163 is processed by the processor 160 in conjunction with reference image data 165 stored in the reference data memory 164.

[00019] Such processing by the processor 160 can be performed in accordance with well known image analysis techniques. For example, the reference data 165 can include data representing or corresponding to any of a number of well known characteristics known to be commonly associated with various medical conditions. For example, such data 165 can represent characteristics commonly associated with breast cancer, including microcalcification clusters, masses or architectural distortions. In the case of microcalcification clusters, the image data 163 may contain image data showing clusters of bright spots, suggestive of microcalcification clusters. Such image data 163 can then, in real time, be compared against and processed with the reference data 165, e.g., using neural

network processing or artificial intelligence techniques. In the event that the result of such processing suggests that such a feature exists, that portion of the image data 163 can be identified as a region of interest for which control signals 17a, 17b are to be generated so as to access more detailed image data 156. Similarly, in the case of masses or architectural distortions, the image data 163 can be compared against and processed with the reference data 165 to determine whether the image data 163 contains data suggestive of such features. If so, the corresponding region(s) of interest can be identified, and appropriate control signals 17a, 17b can be generated for producing, in real time, more detailed and enhanced image data 156.

[00020] Once the stored image 163 and reference 165 data have been processed, and a region of interest within the subject has been identified, control data 161 is provided by the processor to the controller 166, which then provides appropriate control signals 17a, 17b for the detector assembly 14 and x-ray transmitter 12. This process can be repeated until an image of sufficient resolution is produced, e.g., with sufficiency of the resolution being determined either by the user in real time during the imaging process (e.g., by viewing the displayed image), or by the controller 166 based upon whether further processing (e.g., comparison) of the incoming image data 15b (as represented by the stored image data 163) with the reference data 165 yields any further image information beyond some predetermined minimum.

[00021] Referring to Figure 3, the effect of image resolution enhancement in accordance with the presently claimed invention can be better understood. During initial exposure of the subject 9 to x-ray radiation 13a, the otherwise normal full field of view 30 for

the imaging system is restricted to a smaller field 31a by use of the collimator 12b in accordance with well-known principles. This collimated image field 31a produces image data 15b representing an image 33 corresponding to such collimated field 31a. Based upon processing within the control system 16, a region of interest 32 is identified within the collimated field 31a. Such region of interest 32 corresponds to image data 15b representing a particular region 34a within the image 33. Accordingly, the processor 160 produces control data 161 for the controller 166 to produce appropriate control signals 17a, 17b for the detector assembly 14 and x-ray radiation transmitter 12. In accordance with well-known imaging system control techniques, such control signals 17a, 17b can be used to control biasing or dynamic range of the detector assembly 14, as well as voltage or current driving the x-ray tube within the x-ray source 12a, control signals for the focal spot (e.g., size, location or shape) within the x-ray source 12a, and collimation of the transmitted x-ray radiation 13a.

[00022] Based upon control signals 17bb to the collimator 12b, further collimation may be performed such that the collimated field 31b is reduced to focus exclusively on the identified region of interest. With such increased collimation, as well as other modifications to the imaging parameters, as discussed above, the resolution of the identified region of interest 34a is accordingly increased to produce image data representing an image 34b having enhanced resolution.

[00023] Referring back to Figure 1, the extent of the control that can be provided by the control system 16 over the x-ray radiation transmitter 12 and detector assembly 14 can include not only the control features discussed above, but also physical positioning controls.

As will be readily understood, the subject 9 will be disposed substantially between the x-ray radiation transmitter 12 and detector assembly 14 in a spatial relation 11a with the x-ray radiation transmitter 12 and in another spatial relation 11b with the detector assembly 14, with such spatial relations 11a, 11b having three dimensions (e.g., along the x-, y- and z-axes). Accordingly, the region of interest 11 within the subject 9 will also have corresponding spatial relationships with the x-ray radiation transmitter 12 and detector assembly 14 (with such region of interest 11 being defined as that portion of the subject 9 to which the subject radiation 13a is to be applied).

[00024] As part of the control signals 17b provided to the x-ray radiation transmitter 12, additional control signals 17bc can be provided to control physical positioning of the x-ray radiation transmitter 12, e.g., through the use of some form of electromechanical assembly (not shown, but many types of which are well known in the art) for positioning the x-ray radiation transmitter 12 as desired. Similarly, additional control signals 17c can be provided to the detector assembly 14 for controlling the physical positioning of the assembly 14, e.g., via some form of conventional electromechanical assembly (not shown), for physical positioning of the detector assembly 14 as desired. Further similarly, still further control signals 17d can be provided for controlling the physical positioning of the subject (and, therefore, the physical positioning of the region of interest 11), e.g., also via some form of conventional electromechanical assembly (not shown), for positioning the physical location of the subject 9 as desired. Accordingly, the spatial relations 11a, 11b of the subject 9 (and region of interest 11) to the x-ray radiation transmitter 12 and detector assembly 14 can be controlled as desired in all three dimensions (x, y, z), thereby providing for optimum irradiation of the region of interest 11 within the subject 9.

[00025] This technique of automated image enhancement through amplification of identified regions of interest becomes more important as resolutions of electronic image sensor arrays increase. It has been determined that the maximum resolution of an image that can be perceived by the unaided human eye, e.g., without aid from any optical magnification, is approximately 121 microns of pixel pitch (due to the spacing of cones in the human retina). Typically, it is preferred to read x-rays at actual size i.e., at substantially the same size as the anatomical feature being analyzed. Additionally, as noted above, with the desire to minimize the dosage of x-rays to the patient, it is generally desirable to display and/or acquire the initial x-ray image at normal size for display on a monitor with a minimum pixel pitch of approximately 121 microns. Then, using the techniques as discussed above for image enhancement and amplification of regions of interest, the additional x-ray images acquired for the regions of interest at higher dosages can be done at the higher resolutions of which newer electronic imaging sensors are capable. Accordingly, an appropriately magnified image can then be displayed on the monitor taking advantage of such improved sensor resolution.

[00026] This technique of automated image enhancement can also be applied to images where forms of enhancement other than magnification per se are desired, such as when it is desired that the user be able to visually perceive features which are known, suspected or believed to exist within the subject of the x-ray imaging but such features do not necessarily require magnification. Instead, when such features are detected in the initial or subsequent image data, further radiation can be applied in an appropriate manner (e.g., focusing, collimation or other form of concentration) as discussed above to cause such features to become detectable by the electronic imaging sensors such that the image data

produced allow such features to be visually perceived without magnification. For example, if it is desired to observe features (e.g., size, shape or contours) of the internal organs, such features can be enhanced for viewing as part of the final image without necessarily also requiring magnification of such features.

[00027] While the foregoing discussion has been in the context of medical imaging, it will be readily apparent to one of ordinary skill in the art of x-ray imaging that the x-ray imaging system and method of the presently claimed invention can be readily applied outside the field of medical imaging. For example, various industrial applications that will benefit from the system and method of the presently claimed invention include, among others, non-destructive testing of physical objects (e.g., various articles or materials of manufacture) and screening of packages or cargo (e.g., in the shipping or travel industries).

[00028] Regarding non-destructive testing of physical objects, the x-ray imaging system and method of the presently claimed invention can be applied to look for defects or flaws in an article which may occur during its manufacture or handling. For example, a metal casting can be tested to determine whether any flaws, such as cracks, which are not visible to the naked eye exist by having the control system analyze the x-ray data in conjunction with data representing various models of known or suspected forms of flaws. Clearly, in this type of application, such testing can be simpler in that the amount of x-ray exposure will generally be of less concern.

[00029] Regarding package or cargo screening, the x-ray imaging system and method of the presently claimed invention can be applied by having the control system analyze the x-

ray data in conjunction with data representing various objects of which any general and often specific shapes or image profiles are known.

[00030] Accordingly, an x-ray imaging system and method for automatic image resolution enhancement in accordance with the presently claimed invention can be used in virtually any application in which it would be advantageous to apply successive doses of x-ray radiation in an automated manner so as to obtain successively more detailed images of internal characteristics of the subject.

[00031] Various other modifications and alternations in the structure and method of operation of this invention will be apparent to those skilled in the art without departing from the scope and the spirit of the invention. Although the invention has been described in connection with specific preferred embodiments, it should be understood that the invention as claimed should not be unduly limited to such specific embodiments. It is intended that the following claims define the scope of the present invention and that structures and methods within the scope of these claims and their equivalents be covered thereby.